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Rheological behavior of Peruvian carrot starch gels as affected by temperature and concentration

Kivia M. Albano*, Célia M.L. Franco, Vânia R.N. Telis

UNESP – Universidade Estadual Paulista, Departamento de Engenharia e Tecnologia de Alimentos, Rua Cristóvão Colombo, 2265, 15054-000, São José do Rio Preto, SP, Brazil

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ABSTRACT

Beyond their nutritional importance, starches present a relevant technological role in processed foods. The gelatinization process that occurs during heating of starch suspensions is generally followed by considerable shearing rates, which affects the rheological behavior. This work investigated the rheology of gels produced from Peruvian carrot (*Arracacia xanthorrhiza* B.) starch at different concentrations (2, 6, and 10%) and temperatures (10, 30, 50 and 70 °C), using rheological measurements under steady and oscillatory shear. In addition, the system microstructure was analyzed by optical microscopy around the gelatinization temperature (59.5–61 °C). The gels exhibited shear thinning behavior and high thixotropy. Power Law was fitted to flow curves and the consistency index was affected by temperature and starch concentration. Steady and oscillatory shear measurements showed that the rheological behavior was highly dependent on the fraction of gelatinized starch granules, which in turn was affected by water availability and temperature. Depending on temperature and concentration, Peruvian carrot starch resulted in more viscous or more elastic systems, which could be applied in different gel-like foods. Its low gelatinization temperature contributes to easy cooking and high digestibility, but technological applications must take into account its high susceptibility to intense shearing.

1. Introduction

Starches are the main source of carbohydrates in human diet and have great nutritional and technological importance in processed foods, as well as a wide range of non-food applications, including pharmaceuticals, fertilizers, paper, adhesives, textiles, and oil drilling. Functional properties, such as gelatinization temperature, gel formation and paste viscosity define their industrial use. The composition and structure of starch granules vary with botanical source, affecting its properties and functionality (Peroni, Rocha, & Franco, 2006; Singh, Kaurb, & McCarthy, 2007). As the industry demands for new technological properties, several non-conventional starch sources have been studied due to the interest in using native starches for food production instead of using chemically modified starches (Copeland, Blazek, Salman, & Tang, 2009; Matsuguma et al., 2009).

One of the possible alternative sources of starch is Peruvian carrot (*Arracacia xanthorrhiza*, Bancroft). Peruvian carrot, also known as arracacha, is a root vegetable from the Apiaceae family, the same as celery and carrot, originally from the Andean South America. The edible portion of the plant consists of six or more tuberous roots that may be elongated, cylindrical or conical, about 4 cm thick and up to 20 cm long, and covered with thin, lustrous skin. The interior may be white, or yellow to yellowish orange, but the yellow cultivar is the major commercial representative. Commercial production of Peruvian carrot concentrates in South America, especially in Brazil, Colombia, Venezuela, and Ecuador and, on a smaller scale, in Peru and Bolivia. The high prices achieved and the rusticity of the culture, in addition to its reputation of being a healthy product have encouraged its cultivation in Brazil, where the average productivity is around 9 tons per hectare. Nevertheless, the selection of new genetic material in combination to improved agricultural techniques have already resulted in yields higher than 20 tons per hectare (Hermann, 1997; Madeira & Santos, 2008; Portz, Martins, & Baldani, 2004).

The arracacha roots are essentially energetic food, presenting an average of 25 g of carbohydrates per 100 g of root. Although being a good source of vitamin A and niacin, it also presents significant levels of minerals such as calcium, phosphorous and iron, and may be characterized as a nutraceutical food recommended for children,

* Corresponding author. Tel.: +55 17 32212255; fax: +55 17 32212299.
E-mail address: kivia_engalimentos@yahoo.com.br (K.M. Albano).

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elderly and convalescent people nourishment. From the total carbohydrates, the major fraction (about 80%) corresponds to starch (Bueno, 2004; Rocha, Demiate, & Franco, 2008). Peruvian carrot starch displays special characteristics, which make it appropriate for industrial application in many processed foods like soups, infant foods, purees, breads and cakes. It is an easy cooking starch, with low gelatinization temperature, high peak viscosity but susceptible to wearing down due to friction. These characteristics contribute to its high digestibility. It also presents low tendency to retrogradation and to syneresis (Rocha et al., 2008, 2011).

The Peruvian carrot starch has been evaluated for its structural, functional, and physicochemical characteristics, such as granule size and size distribution, degree of crystallinity, amylose content, swelling power, and gelatinization temperature (Matsuguma et al., 2009; Rocha et al., 2008, 2011). Rocha et al. (2008) reported average granule sizes of 11 μm and 14.7 μm, apparent amylose content of 21.67% and 17.81%, and degree of crystallinity 21.4% and 19.7%, respectively for starches extracted from two different cultivars of Peruvian carrot. Evaluation of thermal properties of Peruvian carrot starch indicated that gelatinization occurs in the range of about 57 °C (onset temperature) to 62 °C (peak temperature), involving enthalpy change around of 16 J/g (Rocha, Cunha, Jane, & Franco, 2011, 2008). On the other hand, there is little published information on the rheological behavior of gels prepared from Peruvian carrot starch. Intrinsic viscosity of the starch (around 2.18–2.39) and peak viscosities were determined using the rapid viscoanalyzer (Matsuguma et al., 2009; Rocha et al., 2008).

The Brabender viscoamylograph and rapid viscoanalyser have been extensively used for measuring starch paste viscosity during heating and stirring, but the complex geometry of the measuring system makes it difficult describing the flow profile in the sample. In such a way, fundamental rheological data as function of shear rate, as well as the viscoelastic behavior cannot be determined using these empirical methodologies. Characterization of the rheological properties of Peruvian carrot starch is needed as a first step for permitting its widespread use as an ingredient in food manufacture. In general, the rheological properties of starch gels are strongly influenced by granules swelling and gelatinization. Furthermore, gelatinized starch suspensions may behave as a viscous dispersion, solution, or gel depending on temperature and starch concentration. Experiments under oscillatory shear are a non-destructive means useful to analyze the viscoelastic properties of the starch gels and classifying them into strong and weak gels (Rosalina & Battacharya, 2002). The influence of starch concentration and temperature is also important because these systems can be submitted to different conditions during processing of starch-based products (Kim & Yoo, 2009; Moreira, Chenlo, Torres, & Glazer, 2012).

Based on the above considerations, the objective of this work was to investigate the rheological properties of gels produced from Peruvian carrot starch at different concentrations and temperatures using rheological measurements under steady and oscillatory shear, permitting analysis of their flow curves and mechanical spectra. A second objective was correlating the rheological results with the observed changes in the system microstructure during gelatinization, as evaluated by optical microscopy.

2. Material and methods

2.1. Raw material

Starch was extracted from raw Peruvian carrots (*Arracacia xanthorrhiza*, B., cv. Amarela de Carandaí), cropped after a cultivation period of about 10 months around the city of Piedade, SP, Brazil.

2.2. Starch isolation

Starch isolation was carried out based on the procedure previously described by Rocha et al. (2008, 2011) with small modifications. The roots were washed, peeled, and sliced, followed by grinding in a blender for 40 s at high speed with distilled water at 5 °C and volume ratio of 1:1. The homogenate was passed through a sieve (0.177 mm screen) and the solids retained were subjected to a second grinding (20 s with distilled water at 5 °C; volume ratio of 1:1) and sieved again for extracting residual starch. The total starch suspension, resulting from the first and second grinding steps, was passed through a series of sieves from 80 mesh (0.177 mm) to 200 mesh (0.075 mm) in order to removing fibers and left to stand overnight at 5 °C for decantation. The supernatant was drained by siphoning off and the starch sediment was dried at 38 °C for 24 h in air circulation oven. After drying, the starch was ground in mortar and sieved (0.212 mm screen).

Proximate analysis of the starch was carried out according to the methods recommended by AACC (1995). The total solids content was determined by subtracting the water content. Table 1 presents the compositional characteristics of the isolated starch.

2.3. Gelatinization procedure

Starch gels were prepared at different concentrations (2, 6 and 10 g starch/100 g suspension) in deionized water, taking into account the previously determined starch water content (11.83%, wet basis, as shown in Table 1). Batches of 100 g of suspension were prepared for each concentration and the gelatinization procedure was based on the method described by Paterson, Hardacre, Li, and Rao (2001), aiming to instantaneously raise the temperature of the starch suspension to a predetermined level and guarantee isothermal gelatinization, increasing the uniformity of granule-swelling rates throughout the sample. Initially, the amount of starch required to attain each desired concentration was hydrated with deionized water up to completing 25 g of suspension. This initial suspension was left to stand at room temperature (25 °C) for 10 min and, after that, 75 g of deionized water previously heated to 100 °C were added under manual agitation, making up 100 g of the final suspension. Assuming that the starch dispersion and water have the same specific heat, this procedure leaded the suspension temperature at the beginning of the swelling process immediately to 81.25 °C. Gelatinization was then completed by heating the suspension for 30 min at 90 °C in a thermostatic bath (Rocha et al., 2008) with slight manual agitation to keep uniform temperature inside the sample cup (250 mL glass beaker), followed by cooling at room temperature (25 °C) before the rheological measurements.

2.4. Rheological measurements

The rheological measurements were performed using an AR-2000EX rheometer (TA Instruments, Delaware, USA) with geometry of serrated parallel plates (∅40 mm) and gap of 800 μm, which was adopted based on preliminary results. Samples of 2.0 mL were

Table 1
Compositional characteristics of the starch isolated from Peruvian carrot (*Arracacia xanthorriza*, B., cv. Amarela de Carandaí).

Component	Content (%)
Water	11.83 ± 0.02
Protein	0.45 ± 0.01
Lipid	0.05 ± 0.02
Ash	0.29 ± 0.02